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Guidance Manual for the Application of High-Solids Paints

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
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MARITECH / ASE

PROJECT 3-98-3

**GUIDANCE MANUAL FOR
THE APPLICATION OF
HIGH-SOLIDS PAINTS**

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For

NSRP Technical Panel SP-3

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Guidance Manual for the Application Of High-Solids Paints

I. Purpose

The purpose of this manual is to provide paint shop personnel in the shipbuilding and ship repair industry with guidance and practical methods for the economical application of high-solids paints.

II. Definitions

Air consumption - The amount of air required or used by a spraying operation. Typically expressed in liters per hour or cubic feet per minute.

Base - Typically the "A" component of a two component coating and usually contains the basic resins and pigments that give the coating its desired properties. Another name for the "A" component is resin.

Catalyst - Typically the "B" component of a two component coating and usually contains the ingredients that start the chemical reaction. Other names for the "B" component are hardener, accelerator or kicker.

Dry Spray – When atomized paint particles coming out of the gun do not flow when hitting the surface. Following cure it has the appearance of paint dust or overspray on the surface.

Edge Retention - The dry film thickness of a coating remaining on an edge as compared to the adjacent flat surface. For epoxy paints, the less solvent in the coating the less it shrinks after cure. Lower shrinkage retains more coating on edges.

Epoxy coating – Typically a two component paint consisting of a base and catalyst that when mixed becomes chemically cross-linked through an exothermic reaction to form a protective film.

Exothermic - A type of chemical reaction that produces heat as a by-product.

Flash Point – The lowest temperature of a liquid at which its vapor is given off in sufficient quantities to allow an ignition source to ignite the vapor.

High-Solids Paint – For purposes of this manual, a two-component epoxy paint with at least 80 percent solids by volume.

Hot Potting - The action of manually mixing two component coatings in a container and that causes an exothermic reaction, thereby giving off heat during the chemical reaction of those components.

Hot Spraying - Heating of a coating to reduce its viscosity and make it easier to spray in lieu of using solvents to thin a coating.

Hot work - Production work that produces sparks or flames, such as welding, grinding, cutting or abrasive blasting.

Mix ratio – The prescribed volumes of A and B components that must be mixed. Most high-solids paints are 4:1 ratio, meaning four parts of the “A” component and 1 part of the “B” component (by volume) are mixed together.

Mixing manifold - A device in which previously unmixed base and catalyst components are entered in the proper volumetric ratio, mixed together, and sent to the spray gun

NESHAP – An abbreviation for the "National Emission Standards for Hazardous Air Pollutants", a set of regulations invoked on shipyards by the Environmental Protection Agency. These regulations control various aspects of shipyard painting operations, including the amount of solvent allowed in paints.

Paint Skin – The dried or hard portion on top of liquid paint in the container.

Plural component systems – Paint application systems that use separate pumps for each component of the coating so the mixed material never enters a pump. Plural component systems can be either variable ratio (the volumetric proportions of the components can be changed as required) or fixed ratio (the pumps can only deliver a specific volume of each component with no adjustment ability).

Pot life - The time from initial mixing until a multi-component paint becomes unusable because it has gelled or hardened.

Pump ratio – For a plural component system, the ratio that describes the set volume of paint delivered by each pump. The pump ratio must be in accordance with the mix ratio prescribed by the paint manufacturer.

Purge - To clean or remove liquid paint from a pump or other spray equipment

Single component systems – Paint application equipment that uses a single pump to push the pre-mixed paint through the hose to the spray gun.

Spray life - The time from initial mixing until a multi-component paint can no longer be sprayed and still have an acceptable finish.

Thixotrope – A thickening agent added to paint by the manufacturer that affects viscosity.

Viscosity – A property of liquids that describes its resistance to deformation or flow. Generally, as the thickness of a liquid increases its viscosity and resistance to flow increases.

III. Overview of High-Solids Paints

A. Development

In recent years Federal and State environmental protection agencies have continually reduced the amount of solvent allowed in paints as one method for reducing air pollution. Solvents are typically referred to as "VOCs" which stands for "volatile organic compounds". Many VOCs react with nitrogen oxides in the presence of sunlight to form smog, which is a health hazard. The paint industry responded to the new air pollution regulations by supplying paints with less VOCs per gallon of paint, which increased the amount of "solid" material (the resins, pigments and additives). From this response, the term "high-solids" came into usage to indicate a coating that had more solid material and less solvent per gallon than previously used coatings of the same chemical type. To date, neither the paint industry nor environmental regulations have formally defined "high-solids" paint as having one specific volume of solids. In preparation for developing this manual, a review of paint industry literature indicated the term "high-solids" has been used to describe coatings that range anywhere from 70 percent to 100 percent solids by volume. Because this range is so wide, the term "high-solids" cannot be defined by a single volume of solid material that would be true for all paints. It may be that the term "high-solids" can only be defined on a case-basis for generic classes, such as urethane, epoxy, alkyd, etc., and even those definitions may be constrained by the inherent limitations of formulation chemistry.

During the past 5 years, many shipyards have introduced new paints with less solvent and higher volumes of solids than previously used. A key issue for shipyards is that high-solids paints are often more difficult to apply because their viscosity increased. Thinning of high-solids paints is usually impractical because of regulatory limits on the amount of thinner that can be added and the requirement to keep records on when and how thinning is performed. For most shipyards, the solution is to use high-pressure spray equipment to properly atomize the high-solids paints without thinning.

For the shipbuilding and ship repair industry, two-component epoxy paints typically have the largest usage by volume. These paints are applied to general structure for prevention of corrosion. Traditional epoxy paints for these areas were approximately 50 to 70 percent solids by volume, but are slowly being replaced with paints ranging from 80 to 100 percent solids by volume. For that reason, this guidance manual is focused on the application techniques for high-solids epoxy paints.

B. Chemistry and Fluid Dynamics

For many years, typical shipyard epoxy paints have been based on resin systems produced from the condensation of Bisphenol A and epichlorohydrin. Bisphenol A has good toughness, excellent resistance to many chemicals, and is capable of reacting with many other resins. Aliphatic and aromatic amines, amides, amino resins, polyesters, and phenolics are just a few of the potential curing agents that can be matched with this resin. There are large variations of molecular weights within the Bisphenol A-based epoxies. Typical molecular weights can range from 350 to 4,000 atomic mass units.

The original low molecular weight resins were better suited to adhesives and sealants than paints. These materials were so highly cross-linked that there was insufficient flexibility and impact resistance to make a practical coating. These materials also had long induction times, fast cures with high exotherms, and short pot lives – in short, everything you wouldn't want in shipyard paint! For these reasons, the longer chain, medium weight epoxy resins became the more popular resins system for paints. These resins have molecular weights of 450 to 525 atomic mass units, and were available as solid resins dispersed in aromatic or ketone solvents. Paints made from these resins were usually 45 to 65 percent solids by volume, and had viscosities of 2,000 to 10,000 centipoises. Over the last 25 years, these medium weight epoxy paints became the workhorse coatings for corrosion prevention of ships. However, because the volume of epoxy paint used on ships was so great, the potential for overall VOC-reductions were the greatest if the solvent content of the medium weight epoxy paints could be reduced further.

During the last 14 years, there have been advances in controlling the cross-link density and curing mechanisms for the lower molecular weight resins. Amidoamine and polyamide resins, as well as plasticizers, polyglycol epoxies, and long chain aliphatic diluents have made it possible to create low molecular weight resins with good flexibility. These new resins have the same reactive epoxy groups as previous resins but are attached to a lower viscosity, smaller molecule. This resulted in fast reacting formulations with lower VOC contents and allowed the practical development of high-solids epoxy paints.

High-solids epoxy paints typically have viscosities in the range of 2,000 to 10,000 centipoises, which is considerably higher than that for the medium weight epoxy paints. In some cases only one of the components in two-component epoxy paint systems has a high viscosity, but the viscosity of the mixed components is still higher than that of traditional epoxy paints. The viscosity of these materials is much more easily influenced by temperature changes than were traditional epoxy paints, but it is not possible to generalize the degree of influence for all high-solids paints.

The ability to apply any paint can be influenced greatly by the choice and quantity of thixotropes in their formulations. Addition of a thixotrope typically allows quick recovery to a higher viscosity state after mixing. Materials such as organoclays, fumed silicas, overbased sulfonate gel, polyamide waxes, and castor oil derivatives are the primary materials used as thixotropes. Their use is normally a good thing, in that it allows paints to achieve acceptable sag resistance and good film build after application. However, for high-solids/low VOC coatings, the increase in viscosity that occurs with the use of thixotropes can be a problem. These coatings already have increased viscosities due to their decreased solvent content, and the thixotrope can affect spraying properties even more if not properly selected and quantified. On the positive side, the thixotropic properties of high-solids epoxy paints give them a better ability to retain thickness on edges and corners (commonly called "edge retention") than traditional solventborne epoxy paints. This property is believed to provide a significant improvement in preventing corrosion over the long term.

Reduction of solvent content in two-component epoxy paints also affects pot life. As the volume of solids increase and the solvent content decreases, the epoxy resins and curing

agents are in greater proximity and react faster. With less solvent, there is less dilution of the reactive ingredients, which would normally reduce the frequencies of encounters between the molecules. In addition, with less solvent the heat developed by the exothermic reaction between the ingredients cannot be dissipated as easily from the bulk mass of mixed paint. The presence of this heat increases the rate of reaction, sometimes to the point where the pot life can be shorter than the dry times. For some paints, this creates a situation where even small increases in temperature can result in dramatically shorter pot lives.

The fluid dynamics of high-solids epoxy paints must be evaluated partly in the historical context of paint application methods. Prior to the recent NESHAP limits, many shipyard paints contained a high enough volume of solvent to allow application by conventional spray equipment. On the positive side, this method provided smooth finishes with the low viscosity paints. On the negative side, use of conventional spray equipment resulted in poor transfer efficiency, wastage of paint, and higher solvent emissions to the environment. The introduction of airless spray technology allowed higher viscosity paints to be applied. All shipyards have used 30:1 to 45:1 ratio airless and air-assisted airless pumps successfully for application of 50 to 70 percent solids epoxy paints. By adding thinner to the mixed paint, these pumps are capable of applying the traditional epoxy paints even in cold weather.

The viscosity properties of the new "high-solids" paints have made it difficult to use the standard 45:1 airless pumps. Also, with their short pot lives, there is a potential for gelling and solidifying of the paint while still in the single component pump. Even short delays in the pumping of the mixed material could result in severe damage to equipment.

Epoxy paints are "non-newtonian" fluids. This means that their viscosity changes with the rate of deformation and does not follow Newton's law of viscosity, where the viscosity stays constant with varying shear rates. The behavior of non-newtonian fluids is difficult to predict except in simple situations. Laminar flow (that is, flow in essentially parallel planes of material) of non-newtonian fluids can be understood and modeled, but turbulent flow for non-newtonian fluids is more difficult.

The movement of high-solids paints through the paint pump and spray lines is not considered a problem in and of itself. The manufacturers of spray equipment have developed pumps of adequate power to move these highly viscous paints to the tip of the spray gun. While in the line, the material is considered to be primarily in laminar flow. The paint goes into turbulent flow after it leaves the spray gun. The ability to spray a high-solids coating in a multitude of configurations and to properly atomize the coating at the gun is the key fluid dynamics issue for high-solids coatings.

C. Benefits of High-Solids Paints

In addition to reducing the amount of solvent that is emitted to the environment, the use of high-solids epoxy paints has additional benefits.

- High-solids paints are applied at higher wet film thicknesses per coat, which reduces the total number of coats required and associated labor costs. For example, a 50 percent solid by volume coating may require three coats to achieve a minimum dry film thickness of 8 mils. High-solids paints can provide that same thickness in one coat, thereby saving the labor and material costs for the extra coats. High-solids paints are typically applied at higher dry film thickness to achieve additional corrosion protection benefits without risk of solvent entrapment.
- Another advantage is the edge retention ability of high-solids paints. As the solvent evaporates from traditional solventborne paints, the coatings tend to shrink away from edges. The remaining thickness at the edge may be as low as 40 percent of the thickness on adjacent flat surface areas. Having less solvent, high-solids coatings can retain about 70 percent of their thickness on edges and thereby provide better protection from corrosion and less rework.

D. Selection of High-Solids Paints

The two primary challenges of high-solids coatings over solvent based systems are **increased viscosity** and **shortened pot life**. High-solids paints typically require the use of pumps with pressure ratings of up to 5,000 psi as compared to up to 3,000 psi for the traditional epoxy coatings. Also, the viscosities of the high-solids formulations vary more dramatically with changes in temperature whereas traditional epoxy paints have little viscosity change from temperature. At liquid temperatures of 60°F or lower, high-solids paints have such high viscosities that unacceptable spray properties result, regardless of the spray method used. Conversely, as the temperature of the high-solids paint increases, the viscosity decreases, making it easier to spray. Unfortunately, at higher paint and ambient temperatures, the pot life of a high-solids paint is also reduced. In addition to reduced viscosity and pot life, heating will also reduce the thickness of coating that can be applied to a vertical surface before it sags. All of these factors mean that high-solids epoxy paints have a much more restrictive range of temperatures over which successful application can be achieved. Therefore, for the applicator selection of a high-solids coating must be compatible with the application equipment selected.

The following are the primary criteria for selecting a high-solids epoxy paint for shipyard use:

- The paint should not contain any hazardous materials that make removal costly.
- The paint must meet VOC and OSHA regulations at the location used.
- The paint should have a flash point above 100°F.
- Use light colors to aid in application and inspection, vary colors between coats.
- Pot life should be as long as possible (especially for single component pumps).
- The paint should have a good performance history.

IV. Use of High-Solids Paints

A. Health & Safety Considerations

Health Issues

Prior to use, obtain the Material Safety Data Sheet (MSDS) for the product being used. Read all precautionary notices concerning health and safety. Understanding the recommendations of the coating manufacturer and the proper use of personal protection equipment is absolutely necessary before proceeding. It is strongly recommended that the MSDS be reviewed with an Industrial Hygienist for proper personal protection recommendations before opening the first can of paint.

Some shipyards have noticed an increase in occurrences of personnel receiving skin burns and rashes with some high-solids paints than with traditional epoxy paints. It has been reported that some high-solids coatings seem to penetrate the standard Tyvek suits more easily than traditional epoxy paints. One shipyard switched to a more chemical resistant suit such as Dupont's Tychem 7500 in place of the Tyvek suit, which appears to have reduced the potential for skin contact.

Ventilation is necessary in confined areas when applying high-solids epoxy coatings. High-solids epoxies have little or no odor, but the health hazards from vaporized epoxy/amine vapor still exist and pose health threats. Personal protection and ventilation requirements can not be relaxed due to lower odor.

Fire Hazards

Even with their reduced solvent contents, high-solids paints still have a fire risk associated with them. Therefore, explosion proof electrical equipment is recommended and the appropriate fire fighting equipment should be readily available. OSHA guidelines must be followed regarding coating flash points as related to hot work. The applicator must also be aware that the increased thickness of the high-solids paints creates a potential for the cured coating to sustain a flame. Cases of cured high-solids coatings igniting from welding sparks have been reported.

Safe Equipment Operation

For safe application of high-solids paints, technicians should be qualified for operation of the specific pressure pump system, whether single pump or plural component. It is recommended that technicians receive training from the manufacturer (usually covered in the purchase cost of the equipment) and review the manufacturer's operating documents prior to each use of the equipment.

B. Climate Considerations

Climate conditions vary considerably throughout the country. Most high-solids coatings must be applied to surfaces above 50°F as compared to 35°F for many traditional epoxy paints. Some paint vendors have high-solids paints that can be applied to surfaces below 50°F and 50% humidity or below, but the liquid paint temperature should still be above 70°F during application. In most cases production is optimized with liquid temperatures in the range of 80-110°F. Climatic conditions usually require the use of temperature control, either by using enclosures and/or heating the paint and equipment. See Section J for detailed paint temperature requirements.

Two types of equipment enclosures are common: (1) trailers dedicated for painting operations (for example, a Conex box) and (2) temporary structural enclosures that are erected at the location where painting will occur. Dedicated trailers have proven useful for plural component spray systems and eliminate the labor and material costs for erecting a temporary enclosure at each new job site. The trailer can house both the paint and equipment and can have self-contained heating and cooling capabilities. With either a trailer or temporary enclosure, just the spray lines must extend to the application site. For either method, the spray lines are usually insulated or heated to maintain paint temperature to the gun.

When using single component pumps, the paint temperature must also be controlled during high-solids application. The pumps are typically placed close to the application site due to ease of maneuverability and proximity to the controlled environment to be painted.

C. Equipment Selection Criteria

The most common method of applying high-solids epoxy paints is airless pump pressure spray. This manual focuses on this method because of its high production efficiency.

Touch-up and stripe coating is briefly discussed in this manual, but no one method prevails. The application technique selected is at the preference of the applicator and is dependent on the type of coating selected.

Pump Selection (Single or Plural Component)

Single pump systems are defined as those using a single pump to push pre-mixed two-component epoxy paints through the pump and hose to the spray gun. These pumps should be used when:

- Material usage does not justify plural component system equipment cost.
- Pot life time is long enough to deliver paint through system.
- When several different coatings are being sprayed, thereby requiring constant change outs.
- Size of application area is relatively small.

Plural component pump systems use a pump to push each of the two unmixed components through volume proportioners. Mixing occurs at a static mixhead placed at a desired position. Plural component pump systems are recommended when:

- Material usage is high enough to justify cost of equipment.
- Pot life is short.
- The same coating is being used constantly or few change outs are required.
- Size of area to be painted is relatively large.

Advantages of using **plural component** application over **single component**:

- Pot life concerns are greatly reduced, thereby increasing overall pump life.
- The risk of damaging a pump from gelled or hardened paint is eliminated. Single component pumps can have a cured coating residue or a build up of residue remaining in the pump, which causes problems during future use.
- The amount of waste paint and waste buckets are greatly reduced.
- Painter tender responsibility becomes automated, thereby reducing mixing errors, exposure to liquid paint, and lifting of buckets.
- Consistently accurate mixing process control.

Disadvantages of using plural component over single component pumps:

- Initial cost of plural component systems can be as much as twenty times the cost of single component systems. The Cost section of this report provides an example return on investment calculation.
- Plural component pumps are much larger and usually require a crane or forklift to maneuver.
- The operation of plural component equipment is more complicated and requires more detailed training.

D. Equipment Set-up

The application of high-solids paints requires the use of high-pressure spray equipment and requires the operators to pay strict attention to the manufacturer's safety precautions. Plural component application systems are more complicated than single pump systems and require training even for experienced paint shop personnel. Each equipment vendor has instructions that must be followed exactly for safe operations. For new users of plural component equipment, it is highly recommended that the manufacturer train the user. Only trained and certified personnel should be allowed to operate the equipment. This document will not elaborate on operation of specific vendor's equipment, but provides equipment specifications that work best for applying high-solids epoxy paints.

E. General Spray Requirements

The following single pump and plural component equipment characteristics have been found to be most successful for application of high-solids epoxy paints.

- Airless pump – The pump should have a 60:1 to 80:1 pressure capacity and a 5,000-psi minimum spray line capacity.

- Spray hose - The spray hose should be about 3/8 inch I.D. Heated hoses are not required for ambient temperatures above 40°F. Insulated and/or wrapped hoses are recommended for ambient temperatures below 60°F. To allow the spray gun operator sufficient ease of movement, the length of the spray hose should be approximately the distance from the pump to the extreme outer application area plus 20 percent. Most paint suppliers recommend a maximum of 100 feet in length for single component, but some applicators have used up to 400 feet successfully with plural component pump systems. The US Navy has recommended that hose length should not exceed 200 feet.
- Air supply – The compressor should be capable of supplying a minimum air volume of 50 cubic feet per minute (CFM) at 50-100 psi.
- Air input line – This line should be 1/2 inch I.D. minimum and is typically 3/4 inch I.D.
- Spray gun - The spray gun should be rated for pressures consistent with the airless pump and should have a reversible tip and gun swivel. The tip orifice sizes should range between 0.012 and 0.039 inch. Tip sizes of 5-15 to 5-19 works best with most high-solids epoxy paints. A 5-15 size tip works well for lower viscosity primers and 5-17 for most topcoats.
- Whip Hose – The whip hose should be 1/4-inch diameter by 4-15 foot length to provide flexibility without excessive pressure loss.
- Filters - Use a mesh size as recommended by the coating manufacturer. Typically filter mesh sizes range from 30-60, with 30 used for thicker topcoats and 60 for lower viscosity primers. Filters are pre-installed by the equipment manufacturer. In plural component systems there are usually low-pressure filters in the feed lines and high-pressure filters after the pump leading to the gun. Extra filters should be on hand during spraying operations.
- Pre-heating – Coating pre-heating is typically used to elevate coating temperature to 70°F or higher. The common coating heating methods are in-line heaters, band heaters, drum floor heaters, enclosure ambient, and water baths. Most shipyards are currently using band heaters. It takes at least 1.5 hours to raise a 55 gallon drum of paint from 60° to 100°F with band heaters. The typical band heater power is 1000 watts, 115 volts.
- Mixing – High-solids coatings should never be mixed on a paint shaker since it will entrap air. Mixing shall be conducted by stirring or power mixer.

F. Plural Component Spray Requirements

- Proportioning Pumps – These pumps are typically either electromechanical or mechanical proportioning.

Mechanical pumps use volumetric cylinders that are filled with paint components and pumped on each stroke. They are available in **fixed** or **variable** ratio. Fixed ratio systems proportion at a set ratio, but volumetric cylinders can be changed out. The variable ratio uses a gearbox or a lever action to vary the output of the volume cylinders. Variable ratio machines can provide a range of ratios from 1:1 to 20:1,

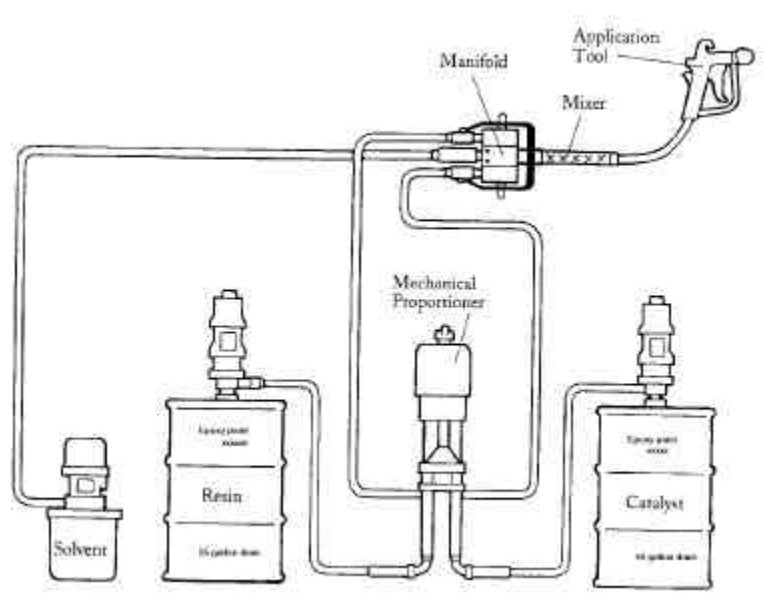
including most any ratio in between. The disadvantage of variable ratio pumps is there are more working parts that can cause an off-ratio mixture or fail. High-solids epoxy paints available today are typically formulated for either a 1:1 or 4:1 ratio of the resin and cure components. Fixed ratio appears to be the better choice if only one or two common ratios are used.

Electromechanical pumps are essentially controlled by electronics or a computer that allow for greater flexibility in ratio control, and feedback on flow rates, coating usage mixing times, etc. The disadvantages are added cost and equipment complexity.

- **Mixing Manifold** – The manifold is supplied by two paint component fluid hoses and one solvent flushing hose. The mixing manifold is the point at which the base and catalyst components are combined by use of a static mixer into a homogeneous mixture of ready-to-apply paint. The mixing manifold can be located close to the point of application to minimize the amount of mixed material in the common line and thereby avoid damage to the system from gelling or hardening. The person switching valves on the mix manifold and the person on the pump must have a method of communication. This is usually achieved by radio headsets or proximity of the items. The mixing manifolds are relatively light, small, and easily positioned near the application area. (For example, 2 foot by 2 foot and 25 lbs.). A 12 element, 9-inch long static mixer is usually adequate for high-solids epoxy paints, although static mixers of 24 inches assure complete mixing.
- **Unmixed Components Hoses**– The general rule is, the higher viscosity component (either resin or cure) requires a slightly larger hose size to compensate for flow rate. This is typically the case with 4:1 ratio mixes where the “A” component (resin) is much thicker than the “B” component (cure). However, the hoses for the “A” and “B” components should be of the same material type so hose expansion is the same.
- **In-line Fluid Heaters** – The fluid heaters heat the un-mixed components at the pump to lower their viscosity, which allows for smoother liquid flow through the system. This is achieved by either circulating the fluid through the reservoir and/or through the heaters and out to the mix manifold. It is important to make sure the fluid temperature remains consistent because changes in temperature can affect viscosity, which in turn will affect mix ratio and sprayability. It is best not to depend on these heaters for high production work since they can’t keep up the heating demand.
- **Solvent Flush Pump** – This pump is typical of plural component systems and is used for cleaning internal parts and hoses exposed to paint. These pumps typically have pump ratios of 32:1-64:1. The 32:1 pump pressure is sufficient to push the remaining fluid out of the hose without atomizing it. Higher pumps ratios of about 64:1 can enable the mixed material left in the system to be sprayed onto the production part. This results in less waste, especially when using long hoses.
- **Coating Material Feed Supply** - Pressure feed pumps and gravity feed systems have both proven to produce very good results with high-solids epoxy paints. Pressure feed systems are most common and reducing the risk of air being introduced into the system, especially when using paints with high viscosities that don’t flow easily without high pressure. **It is important not to allow air to be introduced into the system.** The most common cause of air introduction is depletion of one component

from the feed vessel. The applicator must have a method in place to determine when fluid levels need to be recharged.

- **Ratio Mixing** - Prior to production application, the paint components being pumped from the “A” and “B” hoses **MUST** have a quality control check for proper volume ratio. The equipment manufacturer typically provides the method for performing this check. Being off-ratio 1-2% by volume is generally considered acceptable and should not impact performance of the coating. Being off-ratio 2-5% is cause for reviewing the equipment settings. The ratio should never be more than 5% off.
- **Re-circulation Capability** - Re-circulation capability through the pump system of components is necessary to remove any entrapped air locks and stabilize heating requirements. Re-circulation is conducted by running the main pressure pump and/or the feed pumps. This process is usually in conjunction with operating the in-line heaters to raise components to a desired temperature.
- **Thermometers** - Paint temperature must be checked in the paint component containers and after it comes out of the gun. A method for conducting these measurements should be developed prior to the painting operation is carried out. Probe thermometers are the typical method but a hard-wired thermocouple system is much more efficient for the applicator.



*Figure 1- Typical simplified version of a plural component coating system
(courtesy of GRACO)*

G. Determining Pump Size

Generally, most high-solids epoxy topcoats require up approximately 5,000 psi of pressure to adequately atomize the coatings, equating to a minimum of a 60:1 pump. Several factors such as paint viscosity, temperature, hose length and hose diameter can cause a pressure drop as the paint is forced through the spray system causing insufficient pressure to atomize the paint at the gun. To accurately assess the use of a coating with a particular pump system, it is recommended that a pressure drop

calculation of the system be performed. This calculation must also take into account the amount of flow required from the pump system. For example, the larger the gun tip orifice size and the number of guns used, the greater the demand for pump pressure.

H. Determining Pump Pressure & Flow Rates

The information provided in this guidance manual gives a good overview of standard equipment necessary to apply high-solids coatings. A shipyard may be faced with a situation where this standard equipment cannot be used. The equation below is used to determine fluid pressure drop with selected equipment (for example, when using larger diameter hoses or longer lengths of hose).

The following equation (courtesy of GRACO) can be used for determining the pressure drop in a hose. For plural component pumps this calculation must be done for each of the three spray lines, that is, for the resin component and cure agent lines, and for the mixed material line because each has a different viscosity.

$$\text{Hose Pressure Drop (PSI)} = \frac{V \times L \times FR}{3663 D^4}$$

V = viscosity in centipoise (cP). (The viscosity will vary with temperature)

L = hose length in feet

D = hose inside diameter in inches

FR = flow rate in gallons per minute (at the pump)

The hose pressure drop shall be added to the "coating atomization pressure" to determine the required pump pressure.

The following equation (also courtesy of GRACO) can be used to calculate the required pump flow rate:

$$F = 24 \times G \times D^2 \times \sqrt{\frac{P}{S}}$$

F = flow rate in gallons per minute

P = Pressure in PSI at the gun. Subtracting the hose pressure drop (from the previous calculation) from the pump pressure produces this value.

S = specific gravity (from MSDS. If not available, use 1.5)

D = tip orifice size

G = number of guns

Sample calculations that use these equations are provided in Appendix A.

I. Application Techniques

The application techniques shown below are preferences summarized from manufacturer's data sheets and also represent preferred shipyard methods as identified during the project.

Paint Component Mixing

High-solids epoxy paints separate much less during storage than traditional epoxy paints. The components still need to be thoroughly mixed prior to use to break up coagulated solids. It's important to remove paint skins prior to mixing. Components must be stirred by hand or power mixer with a clean paddle. **Never** put component containers on a shaker, which will produce entrapped air and cause pump application problems.

Spray Pattern Size

Three parameters control spray pattern size: orifice size, fan angle and distance of gun from object to be painted. Three digit numbers identify tips size, e.g.- 519, where the 5 is a fan angle of 10 inches (5x2) and 19 is the orifice size of 0.019 inches.

Orifice tip size controls the amount of coating flowing through the opening. The general rule is, the larger the orifice the faster the flow, and therefore the greater the amount of painter skill required. Tip orifice sizes ranging between 0.012 inch and 0.039 inch and tip sizes of .015 to .019 work best with high-solids epoxy paints.

The shape of the orifice opening determines both fan angle and fan width. The size and shape of the object being painted determine the orifice size selected. A general rule of thumb is the fan pattern should be at least 1/2 the size of the object. For high-solids coating application, fan widths of 8-12" (4-6) are generally preferred. Smaller tips are also recommended for activities such as painting of small pipes or striping.

For the low viscosity primers and stripe coats, the typical tip size is 5-15 or 5-17. For higher viscosity topcoats some shipyards use a 6-17 size tip. For thicker coatings that show tailing and poor atomization, a smaller fan width and larger orifice such as 4-19 to 5-21 can be tried. The painter should have an extra tip assembly in his pocket in case of a clog and access to a 5-gallon bucket to purge the mixed coating from his line.

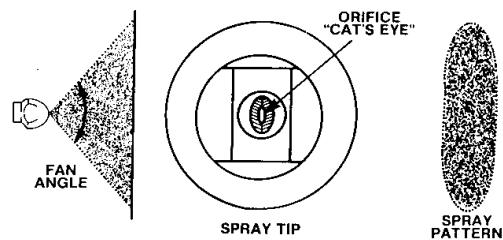


Figure 2 - Fan Angle and Spray Pattern

Tip Wear

Tip wear has a major effect on the quality of a paint job. As a tip begins to wear a distorted spray pattern develops. Noticeable wear of tips can occur after pumping approximately 100 gallons of paint. To maintain the quality of the paint job, it is recommended that the tip be replaced when a change in spray pattern occurs. A good practice is to have enough replacement tips on hand to replace one a day per gun.

Examples of the Effects of Spray Tip Wear

	New Tip	After 30 Gallons	After 100 Gallons	After 150 Gallons
Orifice Size	0.015	0.017	0.019	0.021
Fan Width	12"	11"	9"	5.5"
GPM	0.23	0.30	0.36	0.46
Flow rate increase	NA	30%	61%	100%

Distance to Object

A gun distance of approximately 12 inches produces the best coverage when applying high-solids epoxy paints. As the gun distance from the part increases, the fan width becomes wider, eventually causing an overspray condition and uneven coverage. If the 12-inch distance must be exceeded, select a narrower fan width to retain the spray pattern. All airless tips are sized for a 12-inch spray distance. Also, "Z-swivels" and 18-inch extension wands attached to the spray guns have been very successful for painting hard to reach areas.

Atomization

Atomization occurs with an airless pump system when the paint is pressurized and forced through an orifice that breaks up the material into fine particles.

The two major factors that affect proper atomization are pressure at the gun and material viscosity. The pressure can be adjusted in an airless system to achieve an optimum spray pattern. The pressure required for atomization is based on the viscosity of the paint. Adjusting the spray system's fluid regulator will increase the pressure until the desired pattern is achieved. Lower viscosity paints will almost always produce a finer atomization.

The most common problem associated with the application of high-solids epoxy paints is the coating not atomizing properly. The effect observed is "tailing", which is the coating not atomizing totally and leaving heavy edge tails. Applying the coating at temperatures below optimum application temperature usually causes tailing. Typically, if the temperature of the liquid paint is below 70°F, inadequate atomization of the coating results. Even increases in pump pressure won't atomize the paint properly at low temperatures. When the paint temperature is optimized, it allows for reduction of pressure and/or the capability to add additional spray lines, thereby increasing

productivity. Heating of coatings is discussed in Section J, Temperature Effects for optimum temperatures of high-solids paints.

Application Thickness

High-solids coatings have provided the ability to apply a thicker coating in fewer coats and with virtually no solvent entrapment. This ability increases the life of the coating and corrosion protection of the substrate. However, in every application there are always areas of thickness that exceed the paint manufacturers' recommendations. The manufacturers will typically allow up to two times their recommended thickness without concern for coating performance. The question remains whether or not to remove thicknesses greater than two times the recommended thickness. The concern has been that thicker coating might have a greater tendency to crack in service as a ship's structure flexes, especially as the coating ages. In laboratory testing performed for this task, fully cured coatings were flexed at both the manufacturers' typical recommended thickness of 16 mils and the excess thickness of 50 mils. No increased tendency to crack was detected at 50 mils as compared to the lower recommended thicknesses. These preliminary findings need to be confirmed for long term performance prior to allowing coating thicknesses over 50 mils.

Stripe Coating

Stripe coating should always be done on a surface that has at least one coat of existing paint. Stripe coating application is a "preference of choice" between brushing and spraying. In general, spray striping should be used in a tank with large amount of stiffeners and edges that are easily assessable. Brush striping is necessary in smaller tanks having edges that can't be reached with a gun. Usually a combination of the two methods is the best solution. During spray striping it is best to use a gun tip that delivers a small width and volume of paint for better control. The 4-15 or a 5-15 tips are good sizes to experiment with. The stripe coat color should also be different from the existing coat.

Coating Repair

It has been determined that fully cured high-solids epoxies (typically 7 days to full cure) must have the gloss removed to provide sufficient adhesion of a topcoat. It is recommended the surfaces to be repaired be cleaned to remove all contaminants, abraded to remove or scuff the surface gloss and then re-cleaned. The coating shall then be applied to the vendors recommended thickness.

Painter Communication

Several shipyards have been employing the use of radio headsets for painter communication during tank coating operations. A paint crew typically consists of a crew supervisor, one pump operator, one line tender and three spray painters. The radio communication between the pump operator and line tender was found to be very effective to the efficiency and safety of the coating operation.

J. Temperature Effects

Temperature has a large effect on the **viscosity** and **pot life** of high-solids coatings. Achieving a consistent coating temperature range is the most important controlling factor for achieving a quality application. If the coating temperature is too low it will not atomize properly and if it is too high it will reduce pot life and increase the potential for sag. Overheated paint has been shown to cause “dry spray” during application. If the temperature of a component or mixed paint gets above 160°F, it must be discarded.

Based on laboratory testing and shipyard experiences with high-solids paints, the range of fluid temperatures recommended for plural component applications is **80-110°F**. For single component pump applications, fluid temperatures should be kept in the range of **70-80°F**, although if a coating has a pot life of longer than one hour, the coating temperature may exotherm to 80-90°F, therefore one should pay constant attention to temperature and pot life. Keep in mind that the optimum fluid temperature may vary for different coatings. The more a coating is heated, the faster it will “kick”. For most topcoats, a 100°F temperature will rapidly increase coating viscosity to where it is unsprayable within 20 minutes (See Figure 3 below).

Examples of the variations between fluid temperature and viscosity for several coatings are shown in Figures 1, 2 and 3. These figures show the difference in coating viscosity at three temperatures (60, 80 and 100°F). Most primers have a much lower viscosity than their topcoats, which means that spray equipment settings will vary between primers and topcoats. Through previous sprayability testing of high-solids coatings it was determined that at 60°F most high-solids topcoats used in the marine industry are unsprayable. At temperatures above 80°F, high-solids coating viscosity decreases to the point where sprayability was very consistent. For example, with temperatures of 80°F, the topcoats had a viscosity of about 6,000 cps. Paint with a viscosity of 6,000 cps requires about 4,000-5,000 psi of pressure to properly atomize the coating. It is recommended not to exceed 5,000 psi of operating pressure where possible with most systems available on the market. Therefore, it is important to find a coating below 6,000 cps in viscosity at and applied at an achievable temperature. Note that coatings with viscosities up to 8,000 cps have been successfully applied, but with lower production rates and quality.

IMPORTANT: When coating heating is required, always preheat enough paint material required to finish the job PRIOR to starting production.

With 4:1 ratio high solid paints there is typically a large difference between viscosities of the “A” and “B” components, with the “A” being much thicker than the “B”. A change in coating temperature changes the viscosity of the “A” component whereas the “B” component changes only slightly. This is important in plural component systems where the components are pumped individually through the system. Figure 4 shows the difference in viscosities between “A” and “B” components and how they are affected by temperature. Since each component will have a different flow rate because of different viscosities, adjustments must be made in equipment and/or pump pressures to balance the volume ratios.

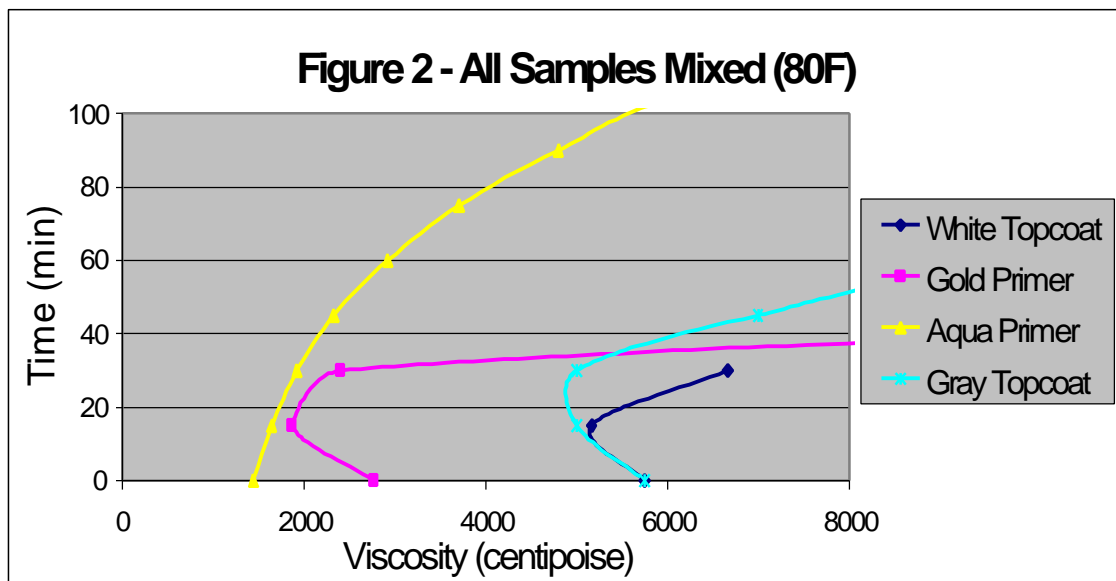
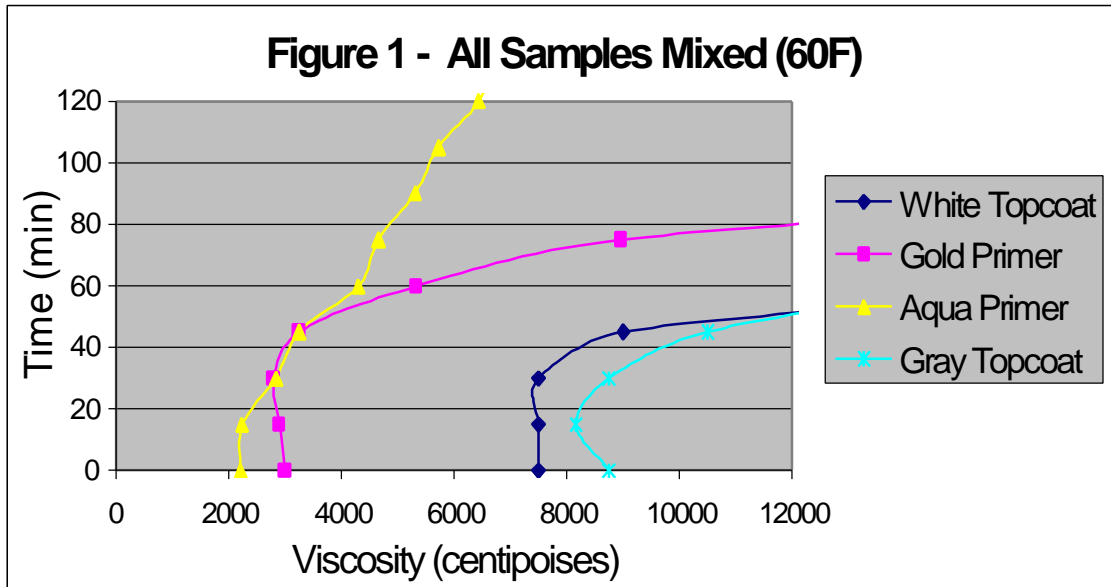
Heating of a coating can be performed by several methods. Most plural component application systems contain in-line heaters and paint re-circulation capability. Re-circulation through in-line heaters can bring the 55 gallon drum liquid components to temperature within 1-2 hours. When the quantities required are greater than the in-line pre-heat capacity, pre-heating should be completed prior to production. Methods of large coating quantity preheating include band heaters, a heated ambient environment or a water bath. From discussions with paint manufacturers, band heaters are the preferred method.

Application pump systems exposed to low ambient temperatures can also cause paint temperatures to drop. The paint loses its heat as it passes through the chilled metal in the spray equipment and hoses. For ambient temperatures below 50°F it is recommended that the application equipment and paint be located inside heated enclosures. Insulated and/or heated hoses may also be required for low ambient temperature conditions.

The following figures show the relationship between temperature and viscosity for four high-solids coatings at three temperatures.

Figures 1-3

These figures show how viscosity changes after mixing four high-solids epoxy coatings at three different temperatures.



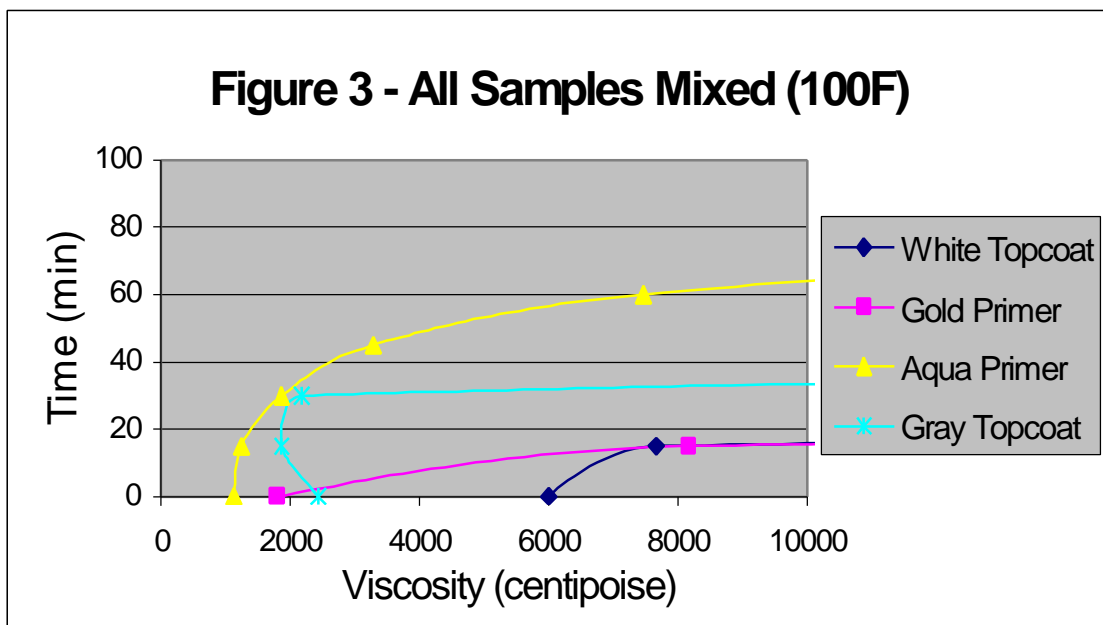
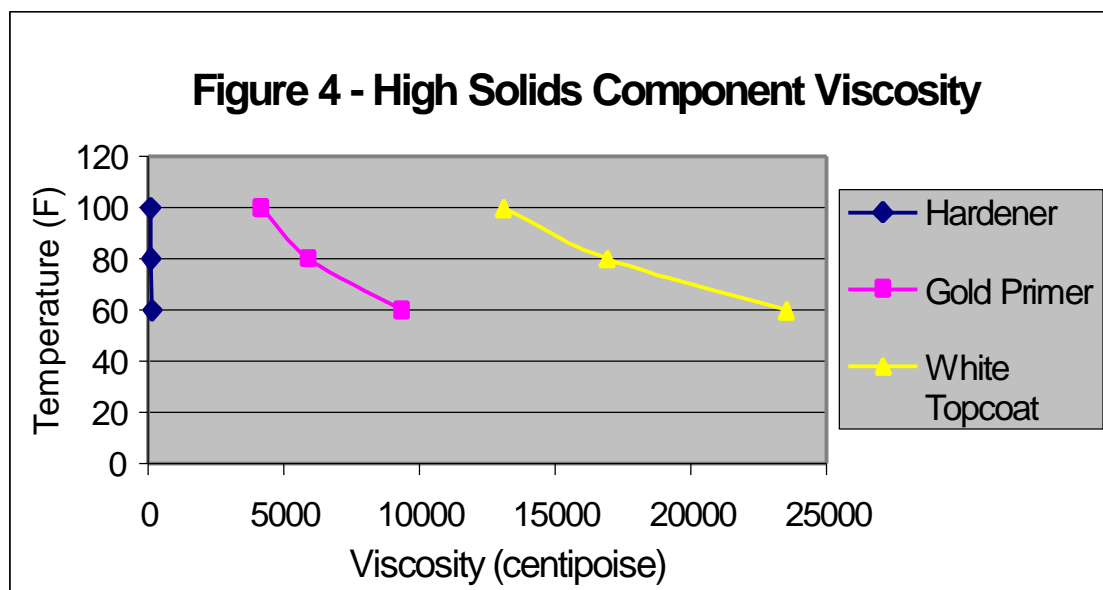


Figure 4

This figure shows the viscosity of the “A” and “B” components at three temperatures.



K. Equipment Clean-Up

Cleaning Solvent Selection

The coating manufacturer will recommend the type solvent to be used for cleaning of high-solids paint from spray lines and pumps. This information is found on the product data sheet for the paint. Once a cleaning solvent has been determined, the chemical compatibility of the solvent(s) with the application equipment components must be determined. Test the solvent prior to using it in the equipment to be sure it can effectively dissolve the paint. The application equipment manufacturer should also give information as to what solvents would be detrimental their equipment.

The following chart gives a general overview of solvent compatibility with typical application equipment materials:

Solvent / Equipment Compatibility Chart

	+	0	X	•	?										
	Recommended	Fair	Probably Unsuitable	Unsatisfactory	Lacking Information										
	Aluminum	Brass	Nitrile Rubber (Buna-N)	Carbon Steel	Polyethylene (UHMW**)	Neoprene	Nylon	303 & 304 Stainless Steel	316 Stainless Steel	400 Series Stainless Steel	Teflon	Thiokol	Viton	Urethane	Leather (Thiokol Impregnated)
*Mineral Spirits or Stoddard Solvent	+	0	+	+		X	+	+	+	+	+	0	+	0	+
Acetate Solvents	+	+	•	0	+	•	+	+	+	0	+	?	?	?	?
*Acetone	+	+	0	+	+	•	+	+	+	+	+	X	•	•	0
Alcohol	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Benzene or Benzol	+	+	•	+	+	•	+	+	+	+	+	X	•	•	0
Butyl Acetate	0	+	•	+	X	•	+	+	+	?	+	0	•	?	?
Butyl Alcohol	0	+	0	0	+	+	+	+	+	+	+	0	?	?	?
*Butyl Cellosolve	?	?	+	+	X	•	?	+	+	+	+	+	0	0	?
Chlorinated Solvents	•	•	•	?	+	•	0	0	+	•	+	X	0	•	0
Ethyl Acetate	X	0	•	0	+	•	+	+	+	?	+	+	•	•	0
Ethyl Alcohol	0	+	+	0	?	+	?	+	+	?	+	+	+	•	0
Ethylene Glycol	0	0	+	+	+	+	+	+	+	+	+	+	+	•	?
Isopropyl Alcohol	+	+	•	+	+	0	+	+	+	?	+	+	+	•	0
Methyl Alcohol (Methanol)	+	+	+	+	0	+	+	+	+	+	+	+	+	•	0
*Methyl Ethyl Ketone	+	+	•	+	0	•	+	+	+	+	+	+	•	•	0
*Methylene Chloride	•	•	•	0	0	•	?	+	+	0	+	•	+	•	•
*Xylene or Xylol	+	+	0	+	•	•	+	+	+	+	+	+	•	•	0
*Toluene or Toluol	+	+	•	+	0	•	+	+	+	+	+	X	+	•	0

Note: Use this information for recommendation only. No guarantee of suitability can be made.

*Most commonly used solvents.

**UHMW — Ultra High Molecular Weight

*For example, one should never use solvents or materials containing halogenated hydrocarbons with equipment containing aluminum wetted parts. An explosion may occur.

Equipment Cleaning

The most important maintenance requirement of a spray system is to completely clean the interior pumps, lines and guns especially if they have been exposed to mixed epoxy paint. Once the mixed paint catalyzes, solvents will no longer remove the paint. An advantage of plural component systems is that mixed paint is never in the pumps, thereby eliminating the risk of ruining the pump with catalyzed material.

With plural component equipment, the unmixed material can be left in the application equipment for several days between uses. Because the cure “B” component in 4:1 ratio coatings has a tendency to crystallize when exposed to air, it is good practice to install a nitrogen or carbon dioxide blanket over the liquid. The “B” component must be examined for “crystallization” prior to each use. If the “B” is crystallized it CANNOT be used and should be discarded. Use of the crystallized material will clog the system, requiring dismantling and meticulous cleaning.

Cleaning Solvent Usage

Generally the use of plural component spray equipment reduces the use of cleaning solvent as compared to single component pump systems. This assumes that only the mixed component lines are being cleaned from the system and the unmixed material is left in the system. If only the mixed spray lines of a plural component system are cleaned solvent usage is typically about 2 gallons.

For most high-solids epoxy paint systems, the primer and topcoat paints are different coatings, which requires that pumps and lines be cleaned or at least flushed prior to using each coating. Shipyards have reported that solvent cleaning of an entire plural component system uses more solvent than a single component pump due to the additional surface area the plural systems employ. Typical solvent usage for complete cleaning of plural pumps and mixed spray lines has been as much as 15 gallons depending on the length of the spray lines and the paint/solvent dissolve rate.

During initial use of new plural component spray equipment, shipyards have used up to 35 gallons for entire system cleaning. It is recommend having at least 55 gallons of cleaning solvent be available for initial cleaning of plural component equipment and the solvent be checked for cleaning compatibility with the coating prior to charging the system.

V. Integration with Shipyard Operations

There are two important factors that a shipyard planner must consider when using high-solids epoxy paints: (1) temperature controls and (2) handling of application equipment.

The coatings must be warmed and held to at least 70°F in order to mix and spray the paint successfully. Shipyard facilities will need a method for warming the paint liquid temperatures colder than 70°F. **Coatings must be heated prior to starting production.** For 55 gallon drums it may require about two hours to warm the contents to this temperature. The contents should also be stirred during heating to distribute the heat. The common heating methods can include heated storage, a water bath, band heaters and/or drum heaters. It is also recommended that the environment for the spray pump, paint and personnel be maintained at temperatures above 50°F. This usually requires heated enclosures when application equipment is in exterior dry dock areas. Some 4:1 ratio high-solids epoxy coatings stored in opened containers (i.e. 55 gallon drums) may require nitrogen or carbon dioxide “blankets” to replace the air in the drum to keep the "B" component from crystallizing.

It is to the advantage of the applicator to have a warm ambient environment during the coating cure cycle. Recoat time is a factor controlled by temperature. For example, a primer may be recoated after 24 hours if it is maintained at 68°F, whereas if it is maintained at 40°F it will require 80 hours cure time. The general rule of thumb for epoxy paint is for every 15°F that ambient temperature is reduced, the cure time will double. Some manufacturers add accelerators to the hardener for faster cure at low temperatures.

The size and weight of plural component equipment can be a limiting factor for accessibility in shipyards. Single component pumps are smaller and lighter and can be maneuvered into small places by the painter. The plural component equipment pallets can range in size from 4 feet x 4 feet x 4 feet to as large as 5 feet x 10 feet x 6 feet. The plural component systems can range in weight from 1,000 to 2000 pounds depending upon the type of equipment. In addition, if 55-gallon drums are used for supplying the coating materials, they can weigh up to 1,300 lbs. Some equipment systems can be mounted on pallets with wheels, whereas most are on fixed pallets that must be moved by fork lift or crane. It is critical for the applicator to predetermine the size and weight capabilities in the shipyard for movement and location of equipment. Once a location is determined, the site must have electrical power and compressed air available. It is also recommended to position the pump above or equal to the height of the application area, where possible, to assist in paint flow.

As stated earlier, once a location is decided, the recommended spray hose length is the distance from the pump to the extreme end of the application area plus 20 percent. It is always recommended to use the least amount of hose length as possible to reduce the amount of solvent needed for cleaning.

VI. Training

Each application equipment manufacturer has a training program for their products. This training is essential for learning the intricate design details of the equipment and to prevent equipment misuse. The primary hazards that can be avoided from proper training are as follows:

Injection Hazards

Spray from the gun, hose leaks, or ruptured components can inject fluid into the body and cause serious injury. Splashing fluid in the eyes or on the skin can also cause injury.

- Keep the gun pointed away from the body.
- Do not "blow back" fluid.
- Follow the pressure relief procedure if the spray tip clogs or if equipment needs to be cleaned.

Fire, Explosion, and Electric Shock Hazards

Improper grounding, poor ventilation, open flames, or sparks can cause fire, explosion or electric shock.

- Ground the equipment and the object being sprayed.
- Electrical wiring must be done by a trained professional and must comply with codes.
- Provide fresh air ventilation.
- Keep hot work and sparks the required distance away.
- Keep area free of debris, solvent and rags.

Toxic Fluid Hazards

Hazardous fluid or toxic fumes can cause serious injury if contacted. Epoxy coatings are considered hazardous materials.

- Know the specific hazards of the fluid being used. The coating manufacturer must provide this information.
- Wear protective eyewear, gloves, clothing and respirator as directed by the shipyard industrial hygiene department.

VII. Cost Analysis

Paint Selection Cost Analysis

This section provides a sample calculation of the difference in material costs for using traditional two-component epoxy paints versus using high-solids epoxy paints. The example will take into account the difference in volume solids, theoretical and practical coverage rates, baseline material costs, and thickness per mil vs. specified thickness, using the following definitions:

Paint price per gallon	Purchase cost of coating, taken from previous purchase information.
Theoretical Spreading Rate	One US gallon of 100% solids paint covers 1,604 square feet of area at a thickness of 1 mil (0.001 inch). Therefore, the theoretical spreading rate is the percentage of solid material (by volume) in the coating multiplied by 1,604.
Practical Spreading Rate	An average of approximately 30% is lost to factors such as residual paint in equipment, buckets and during atomization. This value is determined by multiplying the theoretical spreading rate by 0.7.
Price per mil/sq. ft	The material cost to cover one square foot with one mil of paint.
Cost/sq.ft. at specified mils	The material cost to cover one square foot at the total thickness recommended by the paint manufacturer for the paint system.

	<u>Mil-P-24441 Epoxy Paint</u>	<u>Typical High-Solids Epoxy</u>
Average Price per Gallon	Assume \$22.00	Assume \$46.00
Volume Solids	67%	98%
Theoretical Spreading Rate	$0.67 \times 1,604 = 1,075 \text{ sq. ft./mil/gal}$	$0.98 \times 1,604 = 1,572 \text{ sq. ft./mil/gal}$
Practical Spreading Rate	$1,075 \times 0.7 = 753 \text{ sq. ft./mil/gal}$	$1,572 \times 0.7 = 1,100 \text{ sq. ft./mil/gal}$
Price per mil/sq. ft.	$\$22.00 \div 753 = \mathbf{\$0.029}$	$\$46.00 \div 1,100 = \mathbf{\$0.042}$
Cost/sq.ft. at specified mils	$\$0.029 \times 8\text{mils} = \mathbf{\$0.23}$	$\$0.042 \times 16\text{mils} = \mathbf{\$0.67}$

Therefore, for this example the paint material cost of using the high-solids coatings is about three times the cost of using Mil-P-24441 "Mare Island" solvent based coatings.

Application Equipment Selection Cost Analysis

The following section will help shipyards decide whether single or plural component spray equipment is the best choice for their operation. In general, for the applicator applying large quantities of high-solids paints, plural component systems are the best economic choice. For the applicator applying small quantities of different coatings requiring frequent change-out, single component pumps may be the more cost-effective choice. The initial cost of single component equipment is about \$5,000 whereas the initial cost for high-end plural component systems can range from \$80,000 to \$100,000.

The following cost analysis assumes the use of high-solids epoxy paint systems that have different primers and topcoats, which is typical for the coatings currently available. Each time the coating is changed-out, the application system must be flushed. For a single change-out, the amount of solvent needed to flush a plural component spray system is usually higher than for a single pump spray system due to the increased surface area inside plural units. Equipment manufacturers have reported that for production operations requiring infrequent changes of high-solids coatings (e.g., infrequent changes from primer to topcoats or color changes for the same coating), the unmixed high-solids coatings can remain in the pumps for up to a week without a need for pump cleaning. This reduces the overall labor hours, quantity of cleaning solvent, and wastage of paint.

- Labor Costs

Shipyards have reported that it takes more time to prepare and breakdown a plural component spray system than a single pump system. The saving from using plural component systems comes primarily from eliminating a person to pre-mix the paint by hand. One Navy shipyard has reported a reduction in labor hours for paint application of 16 percent just from this one parameter. The following example shows the labor hours for a typical shipboard tank spray application and assumes the total operation takes about 3 hours.

Line tender 1 person x 3 hours = 3 hours
Pump tender 1 person x 3 hours = 3 hours
Applicators 2 persons x 3 hours = 6 hours
Mixer 1 person x 3 hours = 3 hours

15 total labor labor-hours for single pump spraying

Use of plural component equipment can reduce the total labor by approximately 3 hours by eliminating the need to assign one person to constantly mix fresh paint. Assuming an unburdened labor rate of \$30 per hour for paint shop personnel, plural component equipment can save \$90 per application for this function.

The above savings are predicated on there being just one coating dedicated to the plural component equipment a clean out required for each shift. Coating changing and clean out for plural systems is estimated to require about 3 more labor-hours than single component systems, thereby eliminating any labor savings for each application.

- **Paint Waste Cost**

Plural component systems reduce the amount wasted unused paint by only mixing what is required for the job. Single pump applications typically mix several 5-gallon batches prior to starting the spray application in order to stay ahead of the sprayer. From discussions with several shipyards, this method wastes an average of 2.5 gallons per application, because mixed paint is left over after spraying of the area is completed. Assuming a baseline material cost of \$46 per gallon for high-solids epoxy paint and assuming a \$15 per gallon cost for waste disposal, the wasted paint from the single pump method of spraying would cost an average of approximately \$153 per job. There is also paint left in the spray lines, but this amount is considered about the same for both single pump and plural component systems.

Cost Summary - From the above, it can be summarized that plural component systems have the potential to save about \$243 per application as compared to single pump systems. At a typical shipyard there are about 245 production days a year and assuming two applications a day, the saving could be as much as \$119,000 per year.

For the purpose of this manual, a very simplified economic calculation that determines *annual rate of return* is provided. The annual rate of return on investment is the most commonly used measure of financial efficiency and provides a basis for making an equipment selection.

$\text{annual rate of return} = \frac{\text{annual profit or savings}}{\text{capital invested}}$
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Example: Assume a shipyard performs 40 high-solids applications per year and saves \$243 per application using plural component spray equipment. If the purchase price of plural component equipment is \$90,000, the annual rate of return is 10.8 percent.

$$\begin{aligned}\text{Annual rate of return} &= \frac{(40)(\$243) \text{ (yearly saving)}}{\$90,000 \text{ (plural equipment cost)}} \\ &= 10.8\%\end{aligned}$$

As the number of applications increases, the annual rate of return increases. In many US shipyards, a minimum 10% annual rate of return is the cut-off for deciding on the purchase of new equipment. The cost savings decision to select a single component or plural component pump system is also affected by the size of the area to be coated and the frequency for each application. For example, if a paint shop applies a coating once every two weeks, three hours per shift (thereby requiring full cleaning of the plural component system), then a single pump system may be a better choice. A full clean out of a plural system cancels the labor-hour advantages. On the other hand, continuous (2-7 shifts a week) application of the same coating without change-out gives a cost advantage to a plural component system. The exception would be if the pot life of the coating was so short that there was a serious risk for gelling of the paint in the single pump system before it could be applied.

Examples of Plural Component Equipment



Picture courtesy of Graco



Picture courtesy of WIWA



Picture courtesy of Coverdale Industries

IX. Applicator's Summary for High-Solids Epoxy Application

Selection of High-Solids Paints

High-solids paints typically require the use of pumps with pressure ratings of about 5,000 psi and up to 6,000 psi. Viscosities of the high-solids formulations vary dramatically with changes in temperature. As the temperature of the high-solids paint increases, the viscosity decreases, making it easier to spray. At high temperatures the pot life or working life of a high-solids paint is reduced. In addition to reduced viscosity and pot life, heating will also reduce the sag resistance of the coating

The following are considered the primary criteria for selecting a high-solids epoxy paint for shipyard use:

- The paint should not contain hazardous materials that makes removal costly.
- The paint must meet VOC and OSHA regulations at the location used.
- The paint should have a flash point above 100°F.
- The paint should be available in light and varied colors to aid in application and inspection.
- Pot life should be as long as possible (especially important when using single component pumps).
- The paint should have a good performance history.

Application Pump Selection

Single pump systems are defined as those that use a single pump to push pre-mixed paints through the pump and hose to the spray gun. These pumps should be used for two-component epoxy paints when:

- The quantity of paint used does not justify plural component system equipment cost.
- Pot life time is long enough to deliver paint through system.
- Coating change out is very frequent.
- Size of application area is relatively small.

Plural component pump systems use a pump to push each of the two unmixed epoxy components through volume proportioners. Mixing occurs at a mixhead typically placed at a desired position. Plural component pump systems are recommended when:

- The quantity of paint used is high enough to justify the cost of this equipment.
- Pot life is short.
- Coating change out is frequent.
- Size of area to be sprayed is relatively large.

Training

Each application equipment manufacturer has a training program for their products. This training is essential for learning the intricate design details of the equipment and to prevent equipment misuse.

Application Tips for High-Solids Paints

Storage

- Some 4:1 ratio high-solids epoxy coatings stored in opened containers (i.e. 55 gallon drums) may require nitrogen or carbon dioxide “blankets” to replace the air in the drum to keep the "B" component from crystallizing.

Cleaning Solvent

- During initial use of new plural equipment, shipyards have used up to 35 gallons for cleaning. It is recommend having at least 55 gallons of cleaning solvent be available for initial cleaning of plural component equipment. The solvent should be checked for cleaning compatibility with the coating prior to charging the system. Be sure the solvent selected can dissolve the coating prior to production.

Equipment

- The pump should have a 60:1 to 80:1 pressure capacity and a 5,000-psi minimum spray line capacity
- The spray hose should be about 3/8 inch I.D. Heated hoses are not required for ambient temperatures above 40°F. Insulated and/or wrapped hoses are recommended for ambient temperatures below 60°F. Painters have been known to accidentally pull hoses out of the mixhead connection. To keep this from occurring the spray hose length should be the length from the pump to the extreme end of the application area plus 20 percent.
- The shipyard air compressor should be capable of supplying a minimum air volume of 50 cubic feet per minute (CFM) at 60-100 psi.
- The spray gun should be rated for pressures consistent with the airless pump and should have a reversible tip and gun swivel. Tip sizes of 5-15 to 6-19 work best with most high-solids epoxy paints. A 5-15 size tip works well for the lower viscosity primers and 5-17 for most topcoats. The painter should have an extra tip assembly in his pocket in case of a clog and access to a 5 gallon bucket to purge the mixed coating from his line.
- The most common production problems with high-solids coatings are gun tip and filter clogging. Operators should have extra filters and tips available on site.

Component Mixing Ratio

- An important step prior to production application is the ratio check of the components. The ratio check method is provided by the equipment manufacturer and should be conducted prior to, during and following application of each coating. Because coatings and their components have been shown to have vast differences in viscosities and volume mix ratio, pump equipment and settings must be in sync to provide the correct volume delivery (within 2-5%) of “A” and “B” components to the mix head.
- Air should never be allowed to be introduced into the system because this will throw off mix ratios and pressures. The most common cause of air introduction is depletion

of one component. The applicator must have a method in place to determine when fluid levels need to be replenished.

Paint Temperature

- The range of fluid temperatures recommended for plural component applications is 80-110°F. Also if the temperature of an individual component or mixed paint gets above 160°F, it must be discarded. Shipyard facilities will need a method for warming the paint liquid temperatures. Coatings must be warmed prior to starting production. For 55 gallon drums, it may require about two hours to bring the contents to the 80-100°F temperature range, which must be taken into account when determining production schedules. The contents should also be stirred during heating to distribute the heat. The common heating methods typically include heated storage, a water bath, band heaters and/or drum heaters.
- It is highly recommend that the paint components for the entire quantity required for that shift's production be warmed to a consistent temperature prior to the start of actual spraying.

Curing

- The general rule of thumb for curing of epoxy coatings is: for every 15°F reduction in ambient temperature, the cure time will double. Time between coats for most high-solids epoxy paints is about 12 hours at 70°F.

Coating Repair

- It has been determined that fully cured high-solids epoxies must have the gloss removed to provide sufficient adhesion of a topcoat. It is recommended that the surfaces to be repaired be cleaned to remove all contaminants, abraded to remove gloss and then re-cleaned. The coating shall then be applied to the vendors recommended thickness.

Appendix A

Example of Calculating Hose Pressure Drop

GIVEN: Single component pump
 High-solids topcoat has initial mixed viscosity of 4,000 centipoise
 after "hot-potting"
 150 feet of hose from pump to gun
 Flow rate is 1/3 gallon per minute
 Fluid hose has a 1/4-inch inside diameter

EQUATION: **Hose Pressure Drop (psi) = $\frac{V \times L \times FR}{3663 D^4}$**

Where,

V = viscosity in centipoise (Cp).

L = hose length in feet

D = hose inside diameter in inches

FR = flow rate in gallons per minute (at the pump)

CONVERSION FACTORS:

1 centipoise = 1 Cp = $(1.45 \times 10^{-7}) \text{ lbs} \cdot \text{sec}$

1 foot = 12 inches

1 gallon = 231 in³

1 minute = 60 seconds

CALCULATION:

$$\text{HPD in psi} = (4,000)(1.45 \times 10^{-7} \frac{\text{lbs} \cdot \text{sec}}{\text{in}^2}) (150) (12 \text{ in}) \frac{(231 \text{ in}^3)}{60 \text{ sec}}$$

$$= 48.2 \text{ psi.}$$

The hose pressure drop shall be added to the "coating atomization pressure" to determine the required pump pressure.

Appendix A

Example of Calculating Pump Flow Rate

PROBLEM: Calculate the periodicity for changing spray tips if the goal is to change tips after every 100 gallons of spraying.

GIVEN: Pressure at the gun = 3,500 psi
Specific gravity of the paint = 1.5
Tip orifice size = 0.025 inch
Number of guns used = 1

EQUATION:
$$F = 24 \times G \times D^2 \times \sqrt{\frac{P}{S}}$$

Where

F = flow rate in gallons per minute

P = Pressure in PSI at the gun. Subtracting the hose pressure drop (from the previous calculation) from the pump pressure produces this value.

S = specific gravity (from product MSDS. If not available, use 1.5)

D = tip orifice size

G = number of guns

CALCULATION:

$$F = 24 \times 1 \times (0.025)^2 \times \sqrt{\frac{3,500}{1.5}}$$

F = 0.72 gallons per minute

100 ÷ 0.72 gallons per minute = 139 minutes

Therefore, the spray tip should be changed after approximately every 139 minutes of spraying.

Appendix B

Case Histories

**Sigma Edgeguard Application
4:1 Ratio Using the Graco Supercat Fixed Ratio Pump
Tab Industries,
Pascagoula, Mississippi
February, 1999**

**Courtesy of
John C. McGuckin, Lee Engineering**

Field testing of the Graco Supercat, fixed ratio, plural spray pump using Sigma Edgeguard gray topcoat at Tab Industries, Pascagoula Mississippi, February 10 and 11, 1999

This application was a field test of the 4 :1 ratio Edgeguard topcoat (EX-1713), packaged in 55 Gal. drums, using Graco plural spray equipment.

The Graco Supercat pump and associated equipment was set up inside of Tab Industries' warehouse in Pascagoula, Mississippi. A temporary spray booth was erected to spray out test panels and to demonstrate the actual spray application process of solvent free coatings under simulated field conditions.

The base and catalyst drums were mounted on Graco single lift cylinder 55 gal. drum stands that were provided with air motor driven mixing paddles. No provision was made for recirculation back to the drums. The drums were provided with one band type drum heater that was used to raise the initial drum temperatures to about 80° F. The base and catalyst were then pumped out of the drums using a 10:1 diaphragm pump for the base, and a 1:1 diaphragm pump for the catalyst, through in-line heaters into attached 30 gal. holding tanks. The individual materials were then recirculated through these tanks until the temperature was appx. 95°F. in each tank.

The first coat of Sigma Edgeguard, #EX-1713 gray was sprayed on Tuesday, February 8, 1999 using the following parameters:

- | | |
|---------------------------------------|------|
| • Outside air temperature - | 73°F |
| • Outside RH - | 72 % |
| • Outside steel temperature - | NA |
| • Inside air temperature - | NA |
| • Inside RH - | 72% |
| • Inside steel temperature (panels) - | 73°F |
| • Paint Building temperature - | NA |
| • Base Temperature at drum - | 84°F |

• Catalyst Temperature at drum -	80°F
• Mixed paint at the gun temperature -	90°F
• Air pressure into pump -	50 PSI
• Paint pressure out of pump -	3500PSI
• Number of painters -	1
• Hose size and length -	50 ft. of 3/8"
• Whip size and length -	10 ft. of 1/41/4"
• Tip size -	Graco HD RAC 5-17
• Gun -	Graco standard
• Average DFT (per pass/coat)	12-14 Mils
• Consumption -	8 gal.(test matl.)

The application demonstration went smoothly and we were able to get a good spray pattern with no fingering by starting at 3000 PSI discharge pressure and increasing in 100 PSI increments until the pattern was satisfactory.

A second coat was sprayed on Thursday, February 11 under virtually the same parameters.

The consumption instrumentation readout for paint and solvent is particularly valuable. The manual volumetric function works well and is a good check of the process.

The drying time at these temperatures was appx. 8 hours and the material was hard enough to handle and walk on after 12 hours.

The clean up/solvent flush procedure consisted of flushing the mixing block, static mixer, hose, whip and gun with solvent. The catalyzed material wasted during clean up was approx. 0.5 gal. and the solvent used to clean up was 0.7 gal. For each additional 50 ft. length of 3/8" hose, you will lose an additional 0.4 gal. of paint and 0.4 gal. of solvent.

Uncatalyzed material was left in the pump, guns and tanks, after bringing the heat back up the next morning we started to paint.

Sigma Edgeguard topcoat, 4:1, EX-1713 gray, worked well in a field environment and no problems were experienced with the mixing, spraying or curing.

The Graco Supercat, #232-721, plural spray pump is an easily controlled and robust piece of equipment. It is suitable for applying high solid epoxies.

The following are general recommendations to improve the efficiency and durability of this operation:

- Pipe the transfer pump discharges directly into the pump suction.
- Provide a recirculation line from the heater discharges to the bottom of the 55 gal. drum stands (hose and pipe).
- Provide a permanent temperature pick up on the bottom of the transfer pump suction pipes to read manually and digitally on the system read out.

- Provide a temperature pick up on the inlet of the mixing block for both the base and hardener.
- Change the 55 gal. drum stand to a double cylinder configuration.

The equipment used was:

- Pump – Graco Supercat Model #232-721, plural spray pump, 4:1 mix ratio, 74:1 air motor, complete with two mixing stands with transfer pumps and mixing motors. The pump was also equipped with two 220 Volt AC in line heaters and a pressurized solvent flushing system. The static mixer is 12” long and the distribution block was set up for 3 hoses. There was one complete hose assembly used consisting of 50 ft. of Graco 3/8” insulated, armor covered, 5000 PSI hose with one 10 ft. x 1/4” whip. The gun was a Graco standard with a Graco reversatip, 5-17 tip for all spraying.
- Drum Heaters – Elctroflex Heat Inc., 55 gal. drum, 1000 watt, 115 volts.

General Comments on Pump and Accessory Recommended Modifications

- Mount a remote thermometer with the sensor at the bottom of the feed pickup tube. The read out should be added to the standard instrumentation.
- Provide a check valve and filter on the bottom of the pick up tube. A check valve will top the flow if the tube or filter needed to be disconnected.
- Remove the 30 gal. holding tanks and pipe the suction of the pumps direct to the discharge of the transfer pumps.
- Provide a “T” fitting with a valve on each suction line to accommodate 5 gal. cans if required.
- Pipe the recirculating line back to the paint drums.
- Provide a temperature checkpoint for the inlet side of the mixing block for both the catalyst and base.
- Provide a high pressure valve assembly on the discharge side of the static mixer to accommodate the need for small quantities of catalyzed material for sampling, touch up and striping

**Sigmaguard BT Application
4:1 Ratio Using WIWA
Plural Spray Equipment
TRF Bangor, Silverdale, Washington
January, 1999**

**Courtesy of
John C. McGuckin, Lee Engineering**

Application of the Sigmaguard BT system to MBT 5, USS Alabama, SSBN 731 at TRF Bangor, January 4, through 8, 1999

This application was the first field trial of the 4:1 ratio BT primer,(EX-1708) and BT topcoat, (EX-1709) packaged in 55 gal. drums using WIWA plural spray equipment.

The # 5A MBT was accessed through the bottom flood ports and a temporary enclosure built from plywood and visqueen was erected between the bottom of the hull and the drydock floor. The enclosure was heated and dehumidified and the pump and accessories were located on the ground directly in front of MBT flood access.

The entire tank was fresh water washed and then abrasive blasted with "Cleanblast copper slag, 16/30 to an average profile of 2.5 to 3 mils. Chloride readings were taken after the tank was cleaned and the average reading was 1.6 µg/sq. cm.

All of the paint was provided in 55 gal. drums and the material was stored in a heated portable storage building which maintained the drum temperature at 57°F.

The base drum was provided with two drum heaters that raised the material temperature prior to passing through the line heaters. Both line heaters were used on the "full or 85" setting. The catalyst drum was not preheated. Both drums were mounted on a WIWA pump stand with a 10: 1 diaphragm transfer pump providing appx. 50 PSI positive pressure on the individual pump suction. The base mixer was provided with two mixing paddles and the catalyst mixer had one mixing paddle.

The paint crew consisted of one supervisor, one pump operator, two line tenders and two spray painters. The pump operator and the painters were in constant communication by means of an FM radio set up with ear plugs and a voice actuated throat mike for the painters and a standard headset and boom mike for the pump operator.

The first coat, Sigmaguard BT primer, # EX-1708 , was sprayed between 0845 and 1200 on Monday, January 4, 1999. The following parameters were observed :

- Outside air temperature - 46°F
- Outside RH - 76%
- Outside steel temperature - 42°F

- Inside air temperature - 54°F
- Inside RH - 46%
- Inside steel temperature - 52°F
- Enclosure temperature - 57°F
- Base temperature at drum - 100°F
- Catalyst temperature at drum - 54°F
- Mixed paint at the gun temperature - 96°F
- Air pressure into pump - 65 PSI
- Paint pressure out of pump - 4400 PSI
- Number of painters - 2
- Hose size and length - 200 ft. of 3/8" with a 15 ft. whip hose
- Tip size - Graco HD RAC GHD 6-17
- Gun - Graco standard gun with swivels
- Average DFT - 6 Mils
- Consumption - 53 gal.

The application was virtually problem free with the exception of the base drum temperature reaching 125°F for a short period of time which resulted in some runs. The drum heaters were shut off at this time and the line heaters were turned down to "40". The drum temperature came back down below 100°F in less than 20 minutes and was maintained at that temperature with a single drum heater set at the lowest setting.

The operating procedure consisted of moving each drum from the temporary storage building using a fork truck with a 55 gal. drum lifter to the individual pump stands. The heating bands were attached and mixing was started immediately. The base and catalyst were circulated through the pump and line heaters and recirculated back to the individual drums. The drum stand tops were raised and lowered several times when the cold drums were placed in service to insure even mixing of any heavy pigments in the bottom of the drums. When the temperature of the base drum reached 100°F, painting commenced.

The second coat (stripe coat), Sigmaguard BT, # EX-1709, was sprayed between 0930 and 1300 on Tuesday, January 5, 1999. The following parameters were observed:

- Outside air temperature - 44°F
- Outside RH - 84%
- Outside steel temperature - 42°F
- Inside air temperature - 54°F
- Inside RH - 48%
- Inside steel temperature - 52°F
- Paint building temperature - 52°F
- Base temperature at drum - 98°F
- Catalyst temperature at drum - 90°F
- Mixed paint at the gun temperature - 94°F
- Air pressure into pump - 70 PSI

- Paint pressure out of pump - 4800 PSI
- Number of painters - 2
- Hose size and length - 100 ft. of 3/8" with a 15 ft. whip hose
- Tip size - Graco HD RAC GHD 5-17
- Gun - Graco standard gun with swivels
- Average DFT - 12 to 20 Mils
- Consumption - 32 gal.

The operating procedure consisted of moving each drum from the temporary storage building using a fork truck with a 55 gal. drum lifter to the individual pump stands. The heating bands were attached and mixing was started immediately. We added one heating band to the catalyst drum and turned it on full. The base and catalyst were circulated through the pump and line heaters and recirculated back to the individual drums. The drum stand tops were raised and lowered several times when the cold drums were placed in service to insure even mixing of any heavy pigments in the bottom of the drums. When the temperature of the base drum reached 98°F, and the catalyst drum reached 90°F, painting commenced. The time needed to raise the temperature of the base and catalyst from 60°F to the indicated temperatures was **one hour and 40 minutes**. After painting started, the drum heaters were turned off and the mixed paint temperature was maintained with the line heaters alone. This was the first time that the edge/stripe coat was sprayed and the results were satisfactory with a definite improvement in time to paint and coverage. The paint crew was enthusiastic about using this procedure and felt that this was a good method of applying this coat.

The third coat, Sigmaguard BT, # EX-1709, was sprayed between 0750 and 1200 on Wednesday, January 6, 1999. The following parameters were observed:

- Outside air temperature - 47°F
- Outside RH - 66%
- Outside steel temperature - 44°F
- Inside air temperature - 54°F
- Inside RH - 48%
- Inside steel temperature - 52°F
- Paint building temperature - 52°F
- Base temperature at drum - 98°F
- Catalyst temperature at drum - 90°F
- Mixed paint at the gun temperature - 95°F
- Air pressure into pump - 65 PSI
- Paint pressure out of pump - 4400 PSI
- Number of painters - 2
- Hose size and length - 100 ft. of 3/8" with a 15 ft. whip hose
- Tip size - Graco HD RAC GHD 5-17
- Gun - Graco standard gun with swivels
- Average DFT - 10 to 14 Mils
- Consumption - 67 gal.

The operating procedure consisted of turning the heater bands on both drums on and bringing the material up to painting temperature as indicated. The heating bands were turned off overnight. We added one heating band to the next base drum and turned it on full while it was still in the paint storage building. The base and catalyst were circulated through the pump and line heaters and recirculated back to the individual drums.

The time needed to raise the temperature of the base and catalyst from 65°F to the indicated temperatures was appx. one hour. After painting started, the drum heaters were turned off and the mixed paint temperature was maintained with the line heaters alone. The base drum was taken off line and the full, preheated drum was placed on the stand in less than 3 minutes. The temperature of the paint in the new drum was 80°F. Appx. 8 gal. of paint was drained out of the old drum and added to the new one, raising the temperature to 85°F. There was no difference in the paint quality when the temperature was lowered and we continued to paint with both drums between 80 and 85° F. We talked constantly to the painters and they had the same spray pattern at the lower temperature. The paint handled well and no problems were encountered.

The drying times between the three coats was no more than 18 hours and the coats were dry to the touch and cured sufficiently to walk on and apply the next coat. The tank heat and DH were maintained around the clock.

The overall job proceeded with minimum problems, no machinery breakdowns and good planning and communications with all personnel involved. Paint wastage was minimal and the overall coating was acceptable to the Customer. The WIWA plural pump and associated equipment is a robust, easily controlled and maintained piece of equipment and is particularly suited for application of high-solids epoxies.

The following are general recommendations to improve the efficiency of this operation:

- Install permanent thermometers with remote probes on each drum mixer assembly with the probe mounted on the pick up pipe at the bottom of the drum and the thermometer gauge mounted on the cross rails in front of the mixer motors.
- Install permanent thermometers with remote probes on the discharge pipes of the line heaters and on the discharge line from the static mixer. The thermometer gauges should be mounted on a common gauge panel under the pressure gauges on the front of the pump.
- Take at least one temperature check at the gun after painting is started by actually spraying into a test cup and using a hand held thermometer to record the temperature. The catalyzed paint can be retained as a permanent record of the ratio quality for that particular job.
- Switch to a 5/15 tip for the primer and edgecoats.

The equipment used was :

- Pump – WIWA 2K Duomix, plural spray pump, 4:1 mix ratio, 70 : 1 air motor, complete with two 55 gal. transfer stands with pumps and mixing motors. The pump was also equipped with two ea. 220 Volt AC in line adjustable heaters and a pressurized solvent flushing system. The static mixer is appx.. 15 inches in length and the distribution block was set up for two hoses. There were two complete hose /gun assemblies consisting of 100 ft. of 3/8” , 5000 PSI hose, with a 15 ft., 1/4” whip and Graco standard spray guns. The tips were Graco reversatip, 6-17’s for the topcoat and 5-17’s for the primer and stripe/edge coat.
- Drum Heaters – Electroflex Heat Inc., 55 gal. drum, 1000 watts, 115 volts.
- Communication Equipment – Conspace Communications FM model # CSI 2100 , three channel with remote ear plug and throat mike setups.

**Jotun 591 Winter Grade Solvent Free Epoxy
Application 4:1 ratio, using WIWA and GRACO
plural spray equipment
TRF Bangor
Application of Jotun 591 Wintergrade Solvent Free
Epoxy in #4 Port MBT of the USS Georgia, SSBN 729,
April, 2000**

Courtesy of
John C. McGuckin, Lee Engineering
and
Randy Cornelius, Jotun Paints

This application was the first field trial of the 4:1 ratio Jotun 591 Wintergrade Solvent Free Epoxy. The material was provided in 5 gal. units and was transferred to 55 gal. drums.

The # 4 port MBT was accessed through the bottom flood ports and a temporary enclosure built from plywood and visqueen was erected between the bottom of the hull and the drydock floor. The enclosure was dehumidified and the pump and accessories were located on the ground directly in front of MBT flood access. No heat was provided.

The entire tank was fresh water washed and then abrasive blasted with "Cleanblast copper slag, 16/30 to an average profile of 4.5 to 5 mils. Chloride readings were taken after the tank was cleaned and the average reading was 1.6 µg/sq. cm.

Both the base and catalyst drums were provided with drum heaters that raised the material temperature prior to passing through the line heaters. Both line heaters were used on the "full or 85" setting. Both drums were mounted on a WIWA pump stand with a 1:1 diaphragm transfer pump providing appx. 50 PSI positive pressure on the individual pump suctions. The base mixer was provided with two mixing paddles and the catalyst mixer had one mixing paddle.

The paint crew consisted of one supervisor, one pump operator, one line tender and three spray painters. The pump operator and the line tender were in constant communication by means of and FM radio set up with earplugs and a voice actuated throat mike for the line tender and a standard headset and boom mike for the pump operator.

The first coat of Jotun 591 Wintergrade, was sprayed between 1000 and 1330 on Wednesday, April 5, 2000. The following parameters were observed:

- Color - Gray
- Base Batch # - 591F 25W #01L4037

• Catalyst Batch # -	591T 8WG #0114040
• Outside air temperature -	47°F
• Outside RH -	78%
• Outside steel temperature -	44°F
• Inside air temperature -	46°F
• Inside RH -	50%
• Inside steel temperature -	43°F *
• Base temperature at drum -	90°F
• Catalyst temperature at drum -	75°F
• Mixed paint at the gun temperature -	85°F
• Air pressure into pump -	65 PSI
• Paint pressure out of pump -	6300 PSI
• Number of painters -	3
• Hose size and length - hose	200 ft. of 3/8" with a 15 ft. whip
• Tip size -	Graco HD RAC GHD 6-17, (6-19)
• Gun -	Graco standard gun with swivels
• Average DFT -	6 Mils
• Consumption -	53 gal.

*The inside wall of the ballast tank was appx. 50 to 54°F, this reading was for the outside wall.

The base and catalyst were circulated through the pump and line heaters and recirculated back to the individual drums. The drum stand tops were raised and lowered several times when the cold drums were placed in service to insure even mixing of any heavy pigments in the bottom of the drums. After heating the base and catalyst to the indicated temperature, the drum heaters were turned off and the in line heaters were used to maintain the tip temperature.

We encountered some filter clogging on the base side attached filter. Both base and catalyst filters were cleaned and returned to service.

Two of the three guns clogged up just before completion of painting and the tank was finished using the third gun. The temperature of the mixed paint at the gun was 65°F. I feel that the drop in tip temperature contributed the stoppages in the two guns affected.

A touch up coat of primer was applied by hand on Thursday, April 6, 2000.

We attempted to spray the edge coat of Jotun 591 Winter Grade white at 0800 on Friday, April 7, 2000 but we encountered difficulty with the WIWA plural spray pump. There was a mechanical problem with the pump and a Graco Supercat plural spray pump was substituted.

The base and catalyst drums were mounted on Graco single lift cylinder 55 gal. pump stands which were provided with air motor driven mixing paddles. The drums were provided with one band type drum heater that was used to raise the initial drum temperatures to appx. 92° F for the base and 81°F for the catalyst. The base and catalyst were pumped out of the drums using diaphragm pumps directly to the pump suctions. In-line heaters were used to maintain temperature into the mixing manifold.

The edge coat of Jotun 591 Wintergrade, white was sprayed between 1800 and 2130 on Friday, April 7, 2000. The following parameters were observed:

• Color -	White
• Base Batch # -	591F- 01L40439
• Catalyst Batch # -	591T 8WG – 01L4040
• Outside air temperature -	60°F
• Outside RH -	59%
• Outside steel temperature -	48°F
• Inside air temperature -	58°F
• Inside RH -	41%
• Inside steel temperature -	51°F *
• Paint building temperature -	58°F
• Base temperature at drum -	92°F
• Catalyst temperature at drum -	81°F
• Mixed paint at the gun temperature -	95°F
• Air pressure into pump -	90PSI
• Paint pressure out of pump -	5000 PSI
• Number of painters -	3
• Hose size and length -	100 ft. of 3/8" with a 15 ft. whip
• Tip size -	Graco HD RAC GHD 5-17
• Gun -	Graco standard gun with swivels
• Average DFT -	17 Mils
• Consumption -	48 gal. ***
• Base Temperature output of inline heater -	101°F
• Catalyst Temperature output of heater -	100°

*The inside wall of the ballast tank was appx. 51°F, the outside wall was appx. 48°F.

**One of the lines was inadvertently charged before the crew was ready to paint and the paint hardened in the line and gun. Appx. ten gal. of paint was wasted reducing the actual consumption to 38 gal.

The third coat of Jotun 591 Wintergrade was sprayed between 1000 and 1230 on Monday, April 10, 2000. The following parameters were observed:

• Color -	Green
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• Base Batch # -	591F 01L089
• Catalyst Batch # -	591T 8WG 01L4040
• Outside air temperature -	59°F
• Outside RH -	58%
• Outside steel temperature -	54°F
• Inside air temperature -	59°F
• Inside RH -	42%
• Inside steel temperature -	55°F
• Paint building temperature -	59°F
• Base temperature at drum -	74°F
• Catalyst temperature at drum -	77°F
• Mixed paint at the gun temperature -	85°F
• Air pressure into pump -	90 PSI
• Paint pressure out of pump -	4700 PSI
• Number of painters -	3
• Hose size and length - hose	100 ft. of 3/8" with a 15 ft. whip
• Tip size -	Graco HD RAC GHD 5-17
• Gun -	Graco standard gun with swivels
• Average DFT -	132 readings taken – 21.5 mils total t
• Consumption -	66 gal.
• Base Temperature output of inline heater -	101°F
• Catalyst Temperature output of heater -	100°

Suggestions for improved reliability and control of the process:

- Install permanent thermometers with remote probes on each drum mixer assembly with the probe mounted on the pick up pipe at the bottom of the drum and the thermometer gauge mounted on the cross rails in front of the mixer motors.
- Install permanent thermometers with remote probes on the discharge pipes of the line heaters and on the discharge line from the static mixer. The thermometer gauges should be mounted on a common gauge panel under the pressure gauges on the front of the pump.
- Take at least one temperature check at the gun after painting is started by actually spraying into a test cup and using a hand held thermometer to record the temperature. The catalyzed paint can be retained as a permanent record of the ratio quality for that particular job.
- Switch to a 5/15 tip for the primer and edgecoats.

The equipment used was :

- Pump (primer coat)– WIWA 2K Duomix, plural spray pump, 4:1 mix ratio, 70 : 1 air motor, complete with two 55 gal. transfer stands with pumps and mixing motors. The pump was also equipped with two ea. 220 Volt AC in line adjustable heaters and a pressurized solvent flushing system. The static mixer is appx.. 15 inches in length

and the distribution block was set up for two hoses . There were three complete hose /gun assemblies consisting of 100 ft. of 3/8", 5000 PSI hose, with a 15 ft., 1/4" whip and Graco standard spray guns. The tips were Graco reversatip, 6-17's for the primer and topcoat and 5-17's for the stripe/edge coat.

- Pump (edge and stripe coats) – Graco Supercat, plural spray pump, 4:1 fixed ratio, 60:1 air motor, complete with two ea. 55 gal. single piston transfer stands with mixing motors and transfer pumps. The pump assembly was equipped with two ea. 220 volt AC in line adjustable heaters and a pressurized solvent flushing system. The static mixer is appx. 10 inches long and the distribution block is set up for three hoses. The hose/gun assemblies were identical to the WIWA setup.
- Drum Heaters – Electroflex Heat Inc., 55 gal. drum, 1000 watts, 115 volts.
- Communication Equipment – Conspace Communications FM model # CSI 2100 , three channel with remote ear plug and throat mike setups.

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